Relapse 1 week after bracket removal: a 3D superimpositional analysis

Papagiannis, Alexandros ; Koletsi, Despina ; Halazonetis, Demetrios J ; Sifakakis, Iosif

Abstract: OBJECTIVES To measure tooth movement 1 week post-treatment and assess potential correlation with changes invoked during treatment. SUBJECTS AND METHODS Thirty-eight patients were recruited (19 males, 19 females). Polyvinyl siloxane impressions were taken after bracket debonding (T1) and 1 week later (T2) and digitally scanned. During this period no retention was used. The digital casts were superimposed on structures of the hard palate. Translation and rotation of the first molars, canines, and central incisors were recorded. Additionally, movement of these teeth was assessed from the beginning (T0) until the end of treatment (T1). The correlation between the post-treatment relapse (T1-T2) and tooth movement during treatment (T0-T1) was investigated via the Spearman correlation coefficient. RESULTS Relapse was detected and reflected changes in tooth position during treatment. For the first molars (right, left) the correlation between treatment and post-treatment tooth movement was evident in the transverse direction ($r = -0.38$, $P = 0.020$; $r = -0.32$, $P = 0.052$), tipping ($r = -0.40$, $P = 0.015$; $r = -0.34$, $P = 0.034$) and the antero-posterior direction ($r = -0.31$, $P = 0.061$; $r = -0.36$, $P = 0.027$); for the canines (right and left), as rotation around their long axis ($r = -0.55$, $P = 0.003$; $r = -0.58$, $P = 0.002$); for central incisors (right and left) in the antero-posterior direction ($r = -0.55$, $P = 0.000$; $r = -0.48$, $P = 0.03$), transverse direction ($r = -0.43$, $P = 0.07$; $r = -0.32$, $P = 0.047$), and rotation around their long axis ($r = -0.53$, $P = 0.001$; $r = -0.28$, $P = 0.089$). CONCLUSIONS Post-treatment changes in tooth position were mostly related to tooth movement during treatment. The reported correlations may help clinicians predict short-term relapse, evaluate long-term retention need, and design individualized retention schemes.

DOI: https://doi.org/10.1093/ejo/cjaa024

Originally published at:
Papagiannis, Alexandros; Koletsi, Despina; Halazonetis, Demetrios J; Sifakakis, Iosif (2021). Relapse 1 week after bracket removal: a 3D superimpositional analysis. European Journal of Orthodontics, 43(2):128-135.
DOI: https://doi.org/10.1093/ejo/cjaa024

Relapse 1 week after bracket removal: a 3D superimpositional analysis

Papagiannis A[1], Koletsi D[1,2], Halazonetis DJ[1], Sifakakis I[1].

[1]Department of Orthodontics, School of Dentistry, National and Kapodistrian University of Athens, Greece.
[2]Clinic of Orthodontics and Pediatric Dentistry, Center of Dental Medicine, University of Zürich, Switzerland.

Publication

Papagiannis A, Koletsi D, Halazonetis DJ, Sifakakis I. Relapse 1 week after bracket removal: a 3D superimpositional analysis. Eur J Orthod. 2020 Apr 16:cjaa024. doi: 10.1093/ejo/cjaa024. Epub ahead of print.

Abstract

Objectives: To measure tooth movement one week post-treatment and assess potential correlation with changes invoked during treatment.

Subjects and methods: Thirty-eight patients were recruited (19 males, 19 females). Polyvinyl-siloxane impressions were taken after bracket debonding (T1) and one week later (T2) and digitally scanned. During this period no retention was used. The digital casts were superimposed on structures of the hard palate. Translation and rotation of the first molars, canines and central incisors were recorded. Additionally, movement of these teeth were assessed from the beginning (T0) until the end of treatment (T1). The correlation between the post-treatment relapse (T1-T2) to tooth movement during treatment (T0-T1) was investigated via the Spearman correlation coefficient.

Results: Relapse was detected and reflected changes in tooth position during treatment. For the first molars (right, left) the correlation between treatment and post-treatment tooth movement was evident in the transverse direction ($r=-0.38$, $P=0.020$; $r=-0.32$, $P=0.052$), tipping ($r=-0.40$, $P=0.015$; $r=-0.34$, $P=0.034$) and the anteroposterior direction ($r=-0.31$, $P=0.061$; $r=-0.36$, $P=0.027$); for the canines (right and left), as rotation around their long axis ($r=-0.55$, $P=0.003$; $r=-0.58$, $P=0.002$); for central incisors (right and left) in the anteroposterior direction ($r=-0.55$, $P=0.000$; $r=-0.48$, $P=0.03$), transverse direction ($r=-0.43$, $P=0.07$; $r=-0.32$, $P=0.047$), and rotation around their long axis ($r=-0.53$, $P=0.001$; $r=-0.28$, $P=0.089$).

Conclusions: Post-treatment changes in tooth position were mostly related to tooth movement during treatment. The reported correlations may help clinicians

predict short-term relapse, evaluate long-term retention need and design individualized retention schemes.

Introduction

There is insufficient evidence in the literature on which to base orthodontic retention protocols, and thus little agreement between clinicians (1). In-vitro and in-vivo behaviour of biomaterials used for retention, as well as quantification of individual relapse tendency, constitute research fields of limited evidence-based knowledge. Contemporary materials do not always ensure that successful treatment results are maintained in the long term, despite recent advances in medical technology (2). Even when bonded retainers are in place, relapse may still occur (3), while unexpected post-treatment changes, not necessarily related to the pre-treatment malocclusion, may be detected (4, 5). Specific malocclusions or movement patterns bearing a high relapse tendency have been identified (6), but such tendency may differ significantly between patients. Accurate prediction of relapse may be critical for clinical decision-making, regarding the appropriate retention appliance, retention regime, and level of patient cooperation.

Post-treatment tooth movement inevitably occurs; this is considered to be inherent to a system that has undergone major changes within the frame of its equilibrium (7,8,9). The hypothesis tested here was that any tooth micro-movements, within one week after bracket removal, are correlated to tooth position changes during orthodontic treatment, and might thus be an early sign of tooth position changes towards the pre-treatment state, in the long-term.

In this research the focus was on the maxillary arch because the palate serves as a reliable superimposition area that presents long term stability. Several studies have been published reporting on the stability of the palatal rugae as reference for comparison of pre-treatment and post-treatment results (10,11,12).

The main objective of this research was the quantification of the micro-movements of specific teeth short-term after debonding and the evaluation of potential correlations to tooth movements that had occurred during treatment.

Materials and methods

The protocol was approved by the Ethics Committee, School of Dentistry, XXXX (XXXX).

Thirty-eight patients (19 males, 19 females; mean age: 12.2, SD: 1.9, range: 7.7 to 17.6 years), treated at the Department of Orthodontics, School of Dentistry, XXXXXXXXXXXX, were recruited. Written informed consent was obtained from all patients.

Patients with age range from 7 to 18 years at the onset of treatment, Class I/II molar relationship, Little's irregularity index up to 6 mm in the maxillary/mandibular arch (13), presenting no dental anomalies, no missing or impacted teeth and no congenital anomalies/syndromes were included in this study. All were treated non-extraction, with fixed edgewise straight-wire appliances. Treatment plan did not involve orthognathic surgery or orthopaedic forces. At the end of treatment, Class I molar and canine relationship should have been established, with overjet ≤ 2 mm, overbite ≤ 3 mm, no upper or lower crowding and solid interdigitation of the buccal teeth. Mean treatment time was 3.0 years (SD: 1.1, range: 1.3 to 5.3 years).

To evaluate relapse during the first week post-treatment, two polyvinyl-siloxane impressions (Aquasil Ultra LV, Smart Wetting Impression Material, Dentsply Sirona) were taken, one immediately after debonding (T1), and another a week later (T2), on delivery of the upper Hawley retainer. The two impressions were scanned using a structured light 3D scanner (Identica, Medit Co., Ltd, Seoul, Korea), and the resulting digital casts were superimposed on the hard palate. The superimposition area was bounded posteriorly by the line connecting the most distal points of the first molars and excluded a 4 mm band along the gingival margin (Figure 1). This region offered a large surface area for optimal alignment and was considered sufficiently stable during the short one-week period under investigation. Based on this superimposition, using cast T1 as reference, the direction and extent of movement of the central incisors, canines and first molars (#16,13,11,21,23,26) were measured. Tooth movement was recorded in all three directions, as described below.

Overall tooth movement from start (T0) to end of treatment (T1) was also measured. Because the palate may change considerably during treatment, the superimposition area for this period (T0 to T1) was designed as a ‘T’, the horizontal bar being a 5-mm-wide stripe aligned on the third rugae and extending for two thirds of the rugae length, and the vertical bar, 6 mm wide, extending posteriorly until the line connecting the lingual grooves of the 1st permanent molars (14) (Figure 2).

Tooth movements during each period (T0-T1 and T1-T2) were quantified using the corresponding initial positions (T0 and T1, respectively) as reference (Figure 3). A coordinate system was established to measure movement in the transverse (x-axis), anteroposterior (y-axis) and vertical (z-axis) direction (Figure 4). After superimposing the digital casts on the palate, the coordinate system was transferred to the centroid of each reference tooth (at the initial position). A digital copy of the reference tooth model was created and then superimposed by a best-fit method on the final position. The overall movement imposed by the best-fit alignment was recorded as translation of the tooth centroid along the three axes, and rotation of the tooth around the axes. Superimpositions were based on the Iterative Closest Point (ICP) algorithm (15). All superimpositions and measurements of tooth movements were conducted using Viewbox 4 software (dHal software, Kifissia, Greece).

Statistical analyses were performed with SPSS software (IBM Corp., NY, USA) and Microsoft Excel (Microsoft Corporation, Washington, USA). The final sample size (n) was reduced to 37 for the right molar (#16), 28 for the right canine (#13) and 25 for the left canine (#23) due to non-eruption or partial eruption of these teeth in the initial casts. Because several variables showed evidence of non-normality of distribution (Shapiro-Wilk test), non-parametric statistics were used. Correlations in tooth position changes between T0-T1 and T1-T2 were assessed by the Spearman rank correlation coefficient (r). On an exploratory basis, when an outlier was detected for any of the tooth movements assessed, we examined the effect of removing the outlier on the overall strength of the association between tooth position across the two time intervals.

Two weeks after the first analysis, eight patients were randomly selected and analysed again at the T1-T2 period by the same examiner. Intra-observer random and systematic errors were estimated (16).

Results

Random intra-observer measurement error was 0.029 mm for translation (range: 0.017-0.048 mm) and 0.126 degrees for rotation (range: 0.038-0.222 degrees). No systematic error was detected.

Descriptive statistics of the magnitude of tooth movement during treatment (T0-T1), as well as during the first week post-debonding (T1-T2) are presented in Table I and II respectively.

The detected tooth movements during the T1-T2 period generally mirrored the changes in tooth position during treatment (T0-T1). In certain movement types the correlation between these two time slots followed the expected pattern and was statistically significant. More specifically, regarding the right and left molars (#16, 26), negative correlation was observed in the transverse direction (XP) ($r=-0.38$, $P=0.020$; $r=-0.32$, $P=0.052$ respectively), in tipping (XR) ($r=-0.40$, $P=0.015$; $r=-0.34$, $P=0.034$ respectively), as well as in the anteroposterior direction (YP) ($r=-0.31$, $P=0.061$; $r=-0.36$, $P=0.027$ respectively). (Figure 5) Torque changes towards the pre-treatment state were recorded only in the left molar (YR) ($r=-0.31$, $P=0.020$); in the right molar a weak correlation was implied concerning rotation around its long axis ($r=-0.30$, $P=0.071$). (Table III)

The canines (#13, 23), moved to the pre-treatment state by rotating around their long axis (ZR) (right: $r=-0.55$, $P=0.003$; left: $r=-0.58$, $P=0.002$). (Figure 6, Table VI) Also, negative correlation concerning the vertical position (ZP) ($r=-0.317$, $P=0.100$) was observed to the right canine. (Table VI)

Regarding the central incisors (#11,21) return towards the pre-treatment state was detected in the anteroposterior direction (YP) ($r=-0.55$, $P=0.000$; $r=-0.48$, $P=0.03$ respectively), transverse direction (XP) ($r=-0.43$, $P=0.07$; $r=-0.32$, $P=0.047$ respectively), and tooth rotation around the long axis (ZR) ($r=-0.53$, $P=0.001$; $r=-0.28$, $P=0.089$ respectively). (Figure 7) Additionally, the assessment of the right central incisor revealed changes in tipping towards the initial tooth position (XR) ($r=-0.33$, $P=0.044$). (Table V) In this study, thirteen patients had a median diastema before treatment, and only one patient had pronounced labial frenum, however this was not considered clinically significant. The relapse in the diastema observed one week post debonding was detectable (median: 0.16, IQR=0.16, range: 0.09 to 0.97 mm). This relapse was rapidly corrected, as observed clinically, following the delivery of the retention appliance.

The sensitivity analysis showed no remarkable differences concerning the associations between corresponding values, except for the rotation of the left central incisor around its long axis; by removing only one outlier, the correlation coefficient increased from r=-0.28 to r=-0.37 and the P-value dropped below 0.05 (P=0.023).

Discussion

The study was not free of limitations. First, it might have been possible that superimposition procedures for the T0 to T1 timescale might have been prone to changes pertaining to palatal shape due to treatment and growth, while this was not the case for the digital alignment of the T1 and T2 casts, due to the short time interval between the two records and the large superimposition area. The procedure described by Vasilakos et al. (14) was considered as the most reliable and accurate and thus it was followed by the present study. Furthermore, the digital procedure comprising of cast measurements showed high reproducibility and sensitivity in detecting tooth micro-movements of the order of hundredth of a millimetre. Second, and in order to capture all tooth movements in three dimensions of space (X, Y, Z), we performed a large number of correlation tests, inviting the risk of false positive findings. A possible approach to reduce this risk would have been to pool the right and left sides and compute the average for each tooth type. However, this would have resulted in a significant blurring of the estimated effect and would not have allowed for individual side patterns to reveal themselves. Differences in the movement increments between the two sides were detected indeed. In addition, we have provided the absolute values of the detected movements in all planes for a straightforward estimation of the clinical relevancy of the condition. Third, a longer post-treatment period would have been desirable for a more reliable evaluation of relapse movements, but it would not have been ethical to allow for further relapse to occur. As such, we limited observation period to one week. However, measurable relapse was demonstrated even during this short time-span, in several cases, reaching maximum values of 1.5 mm and 4.5 degrees. (Table II) This relapse was reversed within a short period after retainer use.

Molar and canine position, as well as the anteroposterior position of the central incisors, are considered important aspects for the assessment of relapse and the focus was on these tooth units in the present study. The relapse was primarily in line with changes in tooth position during the course of active orthodontic treatment. Some relapse patterns were similar bilaterally, however, some patterns were observed solely on one side. Differences in the type and degree of malocclusion across sides might present themselves as potentially prognostic factors for these “relapse pattern” side discrepancies. Correlations on one side were recorded on the other as well, however, they might be weak. It might be possible that a more prolonged observation period would result in the detection of further tooth movement correlations. For that reason, results revealing tooth movement correlations of considerable amount were highlighted in the tables and discussed in the text, irrespective of whether they reached statistical significance at the well- established and used threshold of $P<0.05$ on both sides, since they may provide useful insights for certain relapse patterns.

It is currently not possible for orthodontists to fully and reliably identify patients at high risk of relapse or even the extent of the potential relapse. As such, all patients should be treated as if they present with a high potential for relapse (9,17,18). Tooth de-rotation patterns have been reported as the most prone movements to relapse (19,20), and this was partially confirmed by the present study, especially for the central incisors and the canines. Evidence from pre-clinical in-vivo animal research has revealed that the extent of this relapse may reach up to 25 percent during the first 2 months following cessation of rotation movement (19). Practices such as over-correction, more pronounced retention periods, proper contouring of the contact points and surgical procedures have been used to reduce rotational relapse tendency (20). The use of laser-aided fiberotomy compared to the conventional fiberotomy methods has been reported as an effective alternative in reducing rotational relapse of the maxillary incisors (21). A recent randomized controlled trial has confirmed this, albeit focusing on the mandibular incisors (22).

Evidence from retrospective studies has shown that the relapse capacity of incisor teeth may amount to nearly half of the treated cases in the long term, while it is certainly more frequent in the mandibular arch (23,24). A number of related factors have been described, namely severe pre-treatment incisor crowding, arch form constriction, arch length deficiency and increased overbite (23); however cast measurements of treated cases before and after orthodontic treatment have failed to effectively predict maxillary crowding relapse in the long term (24). Lyotard et al. examined short-term post-orthodontic changes, at four- week time interval, without any retention appliance. They concluded that relapse indicators were primarily related to mandibular incisor crowding, overjet and interproximal contacts for almost the entire sample under consideration; notwithstanding, there were no statistically significant effects related to maxillary arch crowding (25). This is in accordance to the present study, since during the observation period of one week, no relapse in relation to pre- treatment crowding was seen for the maxillary incisors.

Contrary, relapse potential was observed in the upper central incisors in the present sample, for both the transverse and the anteroposterior dimensions, frequently followed by opening of the midline diastema. This is a movement pattern documented to have been prone to relapse, especially when a removable adjunct is used as the sole means of retention (26). During the retention phase, opening of the maxillary midline diastema has been reported in 60 percent of a sample wearing Hawley appliances as retainers (27). The only identified post- treatment change associated with midline diastema relapse is the proclination of the maxillary incisors, possibly following a treatment correction of their inclination, being substantiated as an increase in their inclination within the post- treatment period (28). Regarding the post- treatment relapse potential of the initially retroclined maxillary central incisors in Class II Division 2 malocclusion in the long term, a mean relapse of approximately 2 degrees within a 3.5 years follow-up period has been reported (29). In such cases, overbite and interincisal angle have been reported to increase as a result of anterior segment post- treatment movements (30).

Maxillary inter- premolar arch expansion during treatment has also been weakly correlated to certain relapse patterns (18). The potential of the expanded arch to relapse to pre- treatment condition after treatment has been well documented (31,32). A long-term follow-up study has identified more frequent relapse in the maxillary intermolar (25.8%) and mandibular intercanine distances (23.9%), compared to the mandibular intermolar (19.0%) and maxillary intercanine (13.8%) ones (32). Crowding alleviation, the type of treatment followed as well as the amount of expansion during treatment were considered important prognostic factors. Arch width increase of 4mm or more and 2.5 mm or more in the intermolar and intercanine distance respectively, were significantly associated with relapse. (32). These findings were confirmed by Abdulraheem et al., who detected a long-term decrease in the mandibular intercanine distance and the available mandibular space in the anterior region. (33) This is in partial agreement with the present study, since relapse in the transverse dimension was observed for the maxillary first molars, but not for the canines.

The use of Class II elastics is typical in treatment of cases presenting Class II malocclusion. The vertical component of the produced forces applied on the canines, may inevitably lead to a potential extrusion during treatment. Intrusion of the right canine after treatment was detected, a finding that may be possibly attributed to the cessation of the Class II elastic forces long before treatment completion, or the application of finishing aesthetic bends comprising intrusive mechanics. Nonetheless, the correlation was weak, and the pattern was not followed by the left canine.

Short treatment duration has been considered to be associated with higher amounts of relapse (18). It has been argued that treatment duration may present a more important factor in terms of relapse potential of a treated case, than the extent of the therapeutic movements and thus the severity of the malocclusion. The retention effect of a treatment with increased duration has been described (18). In the present study mean treatment time was approximately 3.0 years, however, no correlations of relapse increments with duration of treatment were assessed.

Lyotard et al. (25) studied one-month post-orthodontic treatment changes in absence of retention. The variables tested evaluated relative changes in inter- and intra-arch tooth position (i.e. maxillary/mandibular crowding, overbite, overjet, mandibular intercanine width and the American Board of Orthodontics Objective Grading System). In the present study, individual tooth movements (translation and rotation) were measured, 1-week post-treatment, relative to the part of the hard palate mucosa reported to present long-term stability (14). Some of these movements were also found to be correlated to the pre-treatment tooth position. Such early and potentially prognostic relapse tendency in the short-term is considered a valuable contribution towards future attempts to inform upcoming systematic reviews on the topic, which would allow for a more evidence-based clinical decision making.

Abdulraheem et al., (33) studied the long-term relapse after orthodontic treatment with and without a retainer adjunct in the lower arch. They found that anterior crowding, although alleviated at the end of treatment, increased after the removal of the retention wires, while it continued to increase from 3.6 years to 9.2 years post-retention. The Little's Irregularity Index followed a very similar pattern as well. Twenty-six percent of the long-term post-treatment changes could not be related to displacements or rotations before treatment and were thus attributed to growth effects. (33) The present study indicates that certain movement types have shown return patterns to the pre-treatment state, substantiating treatment related effects. The present superimposition mesh is more reliable and accurate on growing subjects (14), however the post-treatment position and rotation discrepancies, not found to be associated with treatment changes, may have been to some extent guided by growth.

Further research shall focus on the possible correlation of "during treatment" and "short-term post-treatment" movements, with the long-term movement patterns. Predictors or associations may help orthodontists opt the most effective or individualized retention scheme to achieve long-term treatment stability. Moreover, as there is no consensus among the clinicians with regard to the duration of the post-retention period, the degree of the micro-movements recorded in the short or long-term might be an indicator about how stringent the retention protocol should be. If significant amount of relapse is seen, retention should be firmly continued. Otherwise, that may not be necessary.

Conclusions

- Changes in tooth position one week after bracket removal were substantially correlated to tooth movements during treatment.
- Significant relapse in the maxillary arch was demonstrated even one week post-debonding, reaching maximum values of 1.5mm for translation and 4.5 degrees for rotation movements.
- The first molars showed a tendency to return to the pre-treatment state in the transverse direction, tipping and the anteroposterior direction.
- The canines, moved towards the pre-treatment state mainly by rotating around their long axis.
- Regarding the central incisors, return towards the pre-treatment state was detected in the anteroposterior direction, transverse direction and rotation around their long axis.

References

1. Littlewood, S.J., Millett, D.T., Doubleday, B., Bearn, D.R. and Worthington, H.V. (2016) Retention procedures for stabilising tooth position after treatment with orthodontic braces. Cochrane Database of Systematic Reviews, (1):CD002283.

2. Eliades, T. and Sifakakis, I. (2016) Clinically Relevant Aspects of Dental Materials Science in Orthodontics. Ch. 6. In: Graber LW, Vanarsdall, Jr. RL, Vig KWL, Huang GJ ed. Orthodontics. Current Principles and Techniques. 6th ed. Elsevier, St. Louis, pp.187-200.

3. Renkema, A.M., Al-Assad, S., Bronkhorst, E., Weindel, S., Katsaros, C. and Lisson, J.A. (2008) Effectiveness of lingual retainers bonded to the canines in preventing mandibular incisor relapse. American Journal of Orthodontics and Dentofacial Orthopedics, 134, 179e1–179e8.

4. Katsaros, C., Livas, C. and Renkema, A.M. (2007) Unexpected complications of bonded mandibular lingual retainers. American Journal of Orthodontics and Dentofacial Orthopedics, 132, 838–841.

5. Shaughnessy, T.G., Proffit, W.R., Samara, S.A. (2016) Inadvertent tooth movement with fixed lingual retainers. American Journal of Orthodontics and Dentofacial Orthopedics, 149, 277-286.

6. Bearn, D.R. (1995) Bonded orthodontic retainers: a review. American Journal of Orthodontics and Dentofacial Orthopedics, 108, 207-213.

7. Proffit, W.R. (1978) Equilibrium theory revisited: factors influencing position of the teeth. The Angle Orthodontist, 48, 175-186.

8. de la Cruz, A., Sampson, P., Little, R.M., Artun, J and Shapiro, P.A. (1995) Long-term changes in arch form after orthodontic treatment and retention. American Journal of Orthodontics and Dentofacial Orthopedics, 107, 518-530.

9. Littlewood, S.J., Kandasamy, S. and Huang, G. (2017) Retention and relapse in clinical practice. Australian Dental Journal, 62, 51-57.

10. Almeida, M.A., Phillips, C., Kula, K. and Tulloch, C. (1995) Stability of the palatal rugae as landmarks for analysis of dental casts. The Angle Orthodontist, 65, 43-48.

11. Hoggan, B.R. and Sadowsky, C. (2001) The use of palatal rugae for the assessment of anteroposterior tooth movements. American Journal of Orthodontics and Dentofacial Orthopedics, 119, 482-488.

12. Van den Linden, F.P. (1978) Changes in the position of posterior teeth in relation to ruga points. American Journal of Orthodontics, 74, 142-161.

13. Little, R.M. (1975) The Irregularity index: A quantitative score of mandibular anterior alignment. American Journal of Orthodontics, 68, 554-563.

14. Vasilakos, G., Schilling, R., Halazonetis, D. and Gkantidis, N. (2017) Assessment of different techniques for 3D superimposition of serial digital maxillary dental casts on palatal structures. Scientific Reports, 7: 5838.

15. Besl, P.J and McKay, N.D. (1992) A Method for Registration of 3-D Shapes. IEEE Trans. On Pattern Analysis and Machine Intelligence. Los Alamitos, CA, USA: IEEE Computer Society, 14, 239-256.

16. Houston, W.J. (1983) The analysis of errors in orthodontic measurements. American Journal of Orthodontics, 83, 382-390.

17. Dugoni, S.A., Lee, J.S., Varela, J. and Dugoni, A.A. (1995) Early mixed dentition treatment: postretention evaluation of stability and relapse. The Angle Orthodontist, 65, 311-20.

18. Lang, G., Alfter, A., Göz, G. and Lang, G.H. (2002) Retention and Stability – Taking Various Treatment Parameters into Account. Journal of Orofacial Orthopedics, 63, 26–41.

19. Lovatt, R., Goonewardenet, M. and Tennant, M. (2008) Relapse following orthodontic rotation of teeth in dogs. Australasian Orthodontic Journal, 24, 5-9.

20. Ahrens, D.G., Shapira, Y. and Kuftinec, M.M. (1981) An approach to rotational relapse. American Journal of Orthodontics, 80, 83-91.

21. Jahanbin, A., Ramazanzadeh, B., Ahrari, F., Forouzanfar, A. and Beidokhti, M. (2014) Effectiveness of Er:YAG laser-aided fiberotomy and low-level laser therapy in alleviating relapse of rotated incisors. American Journal of Orthodontics and Dentofacial Orthopedics, 146, 565-572.

22. Miresmæili, A.F., Mollabashi, V., Gholami, L., Farhadian, M., Rezaei-Soufi, L., Javanshir, B. and Malekshoar, M. (2019) Comparison of conventional and laser-aided fiberotomy in relapse tendency of rotated tooth: A randomized controlled clinical trial. International Orthodontics, 17, 103-113.

23. Kahl-Nieke, B., Fischbach, H. and Schwarze, C.W. (1995) Post-retention crowding and incisor irregularity: a long-term follow-up evaluation of stability and relapse. British Journal of Orthodontics, 22, 249-257.

24. Canuto, L.F., de Freitas, M.R., de Freitas, K.M., Cançado, R.H. and Neves, L.S. (2013) Long-term stability of maxillary anterior alignment in non-extraction cases. Dental Press Journal of Orthodontics, 18, 46-53.

25. Lyotard, N., Hans, M., Nelson, S. and Valiathan, M. (2010) Short-term postorthodontic changes in the absence of retention. The Angle Orthodontist, 80, 1045-1050.

26. Zachrisson, B.U. (1983) The bonded lingual retainer and multiple spacing of anterior teeth. Journal of Clinical Orthodontics, 17, 838-844.

27. Morais, J.F., Freitas, M.R., Freitas, K.M., Janson, G. and Castello Branco, N. (2014) Postretention stability after orthodontic closure of maxillary interincisor diastemas. Journal of Applied Oral Science, 22, 409-415.

28. Sullivan, T.C., Turpin, D.L. and Artun, J. (1996) A postretention study of patients presenting with a maxillary median diastema. The Angle Orthodontist, 66, 131-138.

29. Devreese, H., De Pauw, G., Van Maele, G., Kuijpers-Jagtman, A.M. and Dermaut, L. (2007) Stability of upper incisor inclination changes in Class II division 2 patients. European Journal of Orthodontics, 29, 314-320.

30. Binda, S.K., Kuijpers-Jagtman, A.M., Maertens, J.K. and van 't Hof, M.A. (1994) A long-term cephalometric evaluation of treated Class II division 2 malocclusions. European Journal of Orthodontics, 16, 301-308.

31. Maniewicz Wins, S., Antonarakis, G.S. and Kiliaridis, S. (2016) Predictive factors of sagittal stability after treatment of Class II malocclusions. The Angle Orthodontist, 86, 1033-1041.

32. Kahl-Nieke, B., Fischbach, H. and Schwarze, C.W. (1996) Treatment and postretention changes in dental arch width dimensions--a long-term evaluation of influencing cofactors. American Journal of Orthodontics and Dentofacial Orthopedics, 109, 368-378.

33. Abdulraheem, S., Schütz-Fransson, U. and Bjerklin K. (2019) Teeth movement 12 years after orthodontic treatment with and without retainer: relapse or usual changes? European Journal of Orthodontics, doi: 10.1093/ejo/cjz020

Figure legends

Figure 1. The superimposition mesh for (T1-T2) period.

Figure 2. The superimposition mesh for (T0-T1) period.

Figure 3. Digital cast superimposition for (a) T0-T1 and (b) T1-T2 period, with colour map of the superimposition mesh. Green: T0 period, Grey: T1 period, Blue: T2 period.

Figure 4. Axes of the reference system. Vectors point in the positive direction.

Figure 5. Main relapse patterns of first molars (#16,26). Plots and graphics are indicative and depict correlation between corresponding variables pre- and post-treatment. Green: T0 period, Grey: T1 period, Blue: T2 period. The horizontal axis depicts changes invoked during orthodontic treatment (T0-T1), whereas the vertical axis changes during the post-treatment period (T1-T2).

Figure 6. Main relapse patterns of canines (#13,23). Plots and graphics are indicative and depict correlation between corresponding variables pre- and post-treatment. Green: T0 period, Grey: T1 period, Blue: T2 period. The horizontal axis depicts changes invoked during orthodontic treatment (T0-T1), whereas the vertical axis changes during the post-treatment period (T1-T2).

Figure 7. Main relapse patterns of central incisors (#11,21). Plots and graphics are indicative and depict correlation between corresponding variables pre- and post-treatment. Green: T0 period, Grey: T1 period, Blue: T2 period. The horizontal axis depicts changes invoked during orthodontic treatment (T0-T1), whereas the vertical axis changes during the post-treatment period (T1-T2).

Table legends

Table I. Descriptive statistics of the magnitude of tooth movement (absolute values) during treatment (T0-T1). Position and rotation changes were measured in millimetres and degrees respectively. P: position; R: rotation.

Table II. Descriptive statistics of the magnitude of tooth movement (absolute values) one week after bracket debonding (T1-T2). Position and rotation changes were measured in millimetres and degrees respectively. P: position; R: rotation.

Table III. Spearman correlation coefficient (r) for the first molars between corresponding variables. P: position changes; R: rotation changes. Results in bold are discussed in the text.

Table IV. Spearman correlation coefficient (r) for the canines between corresponding variables. P: position changes; R: rotation changes. Results in bold are discussed in the text.

Table V. Spearman correlation coefficient (r) for the central incisors between corresponding variables. P: position changes; R: rotation changes. Results in bold are discussed in the text.

Table I.

T0-T1	16 X P	16 Y P	16 Z P	16 X R	16 Y R	16 Z R	26 X P	26 Y P	26 Z P	26 X R	26 Y R	26 Z R
25% quartile	0.34	0.69	0.78	2.46	1.40	3.03	0.25	0.54	0.45	2.32	1.49	1.61
50% quartile	0.62	1.27	1.58	4.34	4.35	6.81	0.76	1.41	1.75	4.34	2.76	4.07
75% quartile	1.01	2.92	3.09	8.84	7.23	12.58	1.41	2.15	3.25	9.01	6.76	9.16
maximum	3.88	5.50	5.95	23.90	13.78	25.62	4.80	4.79	7.24	24.45	11.80	19.31
	13 X P	13 Y P	13 Z P	13 X R	13 Y R	13 Z R	23 X P	23 Y P	23 Z P	23 X R	23 Y R	23 Z R
25% quartile	0.40	0.50	0.44	3.96	1.07	3.46	0.49	0.51	0.69	1.96	1.77	2.90
50% quartile	0.75	1.45	1.77	7.05	4.30	6.89	0.89	1.11	1.61	3.82	3.68	6.04
75% quartile	1.65	2.37	2.85	8.99	8.52	15.17	1.68	1.59	2.66	8.02	7.96	14.77
maximum	3.00	4.78	8.06	13.93	31.02	30.19	4.72	4.26	5.35	14.33	13.99	29.21
	11 X P	11 Y P	11 Z P	11 X R	11 Y R	11 Z R	21 X P	21 Y P	21 Z P	21 X R	21 Y R	21 Z R
25% quartile	0.58	0.82	1.10	4.29	2.23	2.10	0.45	0.72	0.66	4.09	1.23	1.47
50% quartile	1.23	2.00	2.33	9.31	4.13	6.45	1.00	1.53	1.97	8.00	3.69	5.48
75% quartile	2.10	2.52	3.07	16.23	7.62	9.24	2.45	2.05	3.46	15.23	5.82	10.34
maximum	3.79	3.77	6.32	43.52	16.01	17.03	3.56	5.52	6.00	38.85	14.00	23.73

Table II.

T1-T2	16 X P	16 Y P	16 Z P	16 X R	16 Y R	16 Z R	26 X P	26 Y P	26 Z P	26 X R	26 Y R	26 Z R
25% quartile	0.04	0.04	0.05	0.26	0.18	0.12	0.02	0.03	0.07	0.23	0.16	0.17
50% quartile	0.09	0.12	0.11	0.64	0.49	0.35	0.07	0.08	0.15	0.68	0.37	0.27
75% quartile	0.14	0.19	0.24	1.35	0.87	0.76	0.15	0.23	0.23	1.07	0.72	0.47
maximum	0.36	0.35	0.57	3.04	2.03	2.60	0.38	0.51	0.70	2.82	2.95	2.70

	13 X P	13 Y P	13 Z P	13 X R	13 Y R	13 Z R	23 X P	23 Y P	23 Z P	23 X R	23 Y R	23 Z R
25% quartile	0.04	0.06	0.05	0.27	0.30	0.26	0.04	0.05	0.04	0.29	0.26	0.56
50% quartile	0.08	0.12	0.12	0.54	0.73	0.68	0.08	0.08	0.09	0.61	0.64	0.96
75% quartile	0.16	0.21	0.20	1.06	1.05	1.50	0.15	0.16	0.18	1.07	1.15	1.63
maximum	0.36	0.39	1.03	2.65	2.40	3.13	0.26	0.58	0.68	2.45	2.69	3.51

	11 X P	11 Y P	11 Z P	11 X R	11 Y R	11 Z R	21 X P	21 Y P	21 Z P	21 X R	21 Y R	21 Z R
25% quartile	0.04	0.08	0.04	0.25	0.29	0.36	0.04	0.07	0.04	0.37	0.23	0.24
50% quartile	0.07	0.14	0.14	0.51	0.61	0.68	0.07	0.15	0.10	0.80	0.43	0.58
75% quartile	0.13	0.26	0.21	1.28	0.96	1.31	0.15	0.25	0.21	1.25	0.70	0.83
maximum	0.28	0.51	1.57	3.78	4.45	1.96	1.28	0.64	1.62	4.51	1.95	2.75

Table III.

		T1-T2	
		#16	#26
T0-T1	X P	**-0.381**†	**-0.318***
	Y P	**-0.311***	**-0.358***
	Z P	-0.155	-0.241
	X R	**-0.397**†	**-0.344**†
	Y R	-0.017	**-0.377**†
	Z R	**-0.300***	-0.098

‡ significant at 0.01 level, †significant at 0.05 level, * significant at 0.10 level

Table IV.

		T1-T2	
		#13 (n=28)	#23 (n=25)
T0-T1	X P	-0.001	-0.292
	Y P	-0.254	-0.200
	Z P	**-0.317**	0.046
	X R	**-0.496‡**	0.093
	Y R	-0.223	0.061
	Z R	**-0.547***	**-0.582‡**

‡ P < 0.01, † P < 0.05, * P < 0.10

Table V.

		T1-T2	
		#11	#21
T0-T1	X P	**-0.432‡**	**-0.324†**
	Y P	**-0.549‡**	**-0.475‡**
	Z P	-0.182	-0.102
	X R	**-0.329†**	-0.192
	Y R	-0.208	0.045
	Z R	**-0.525‡**	**-0.280***

‡ significant at 0.01 level, †significant at 0.05 level, * significant at 0.10 level

Figure 1.

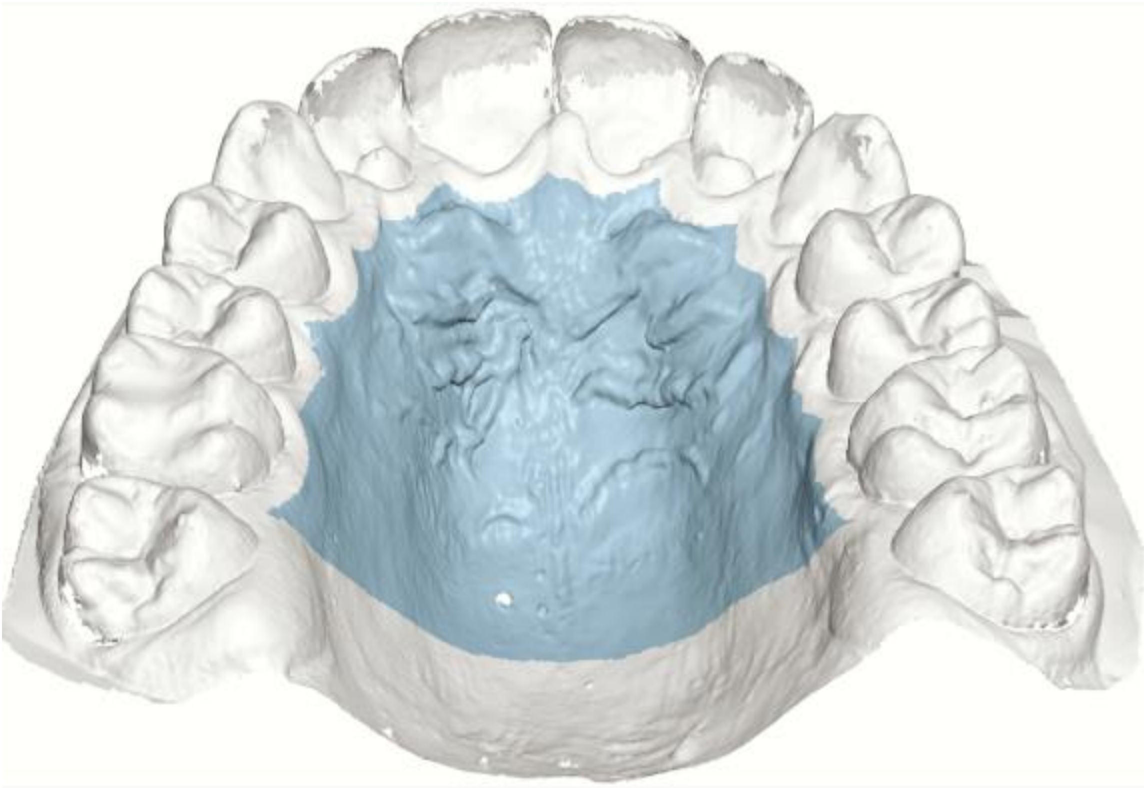


Figure 2.

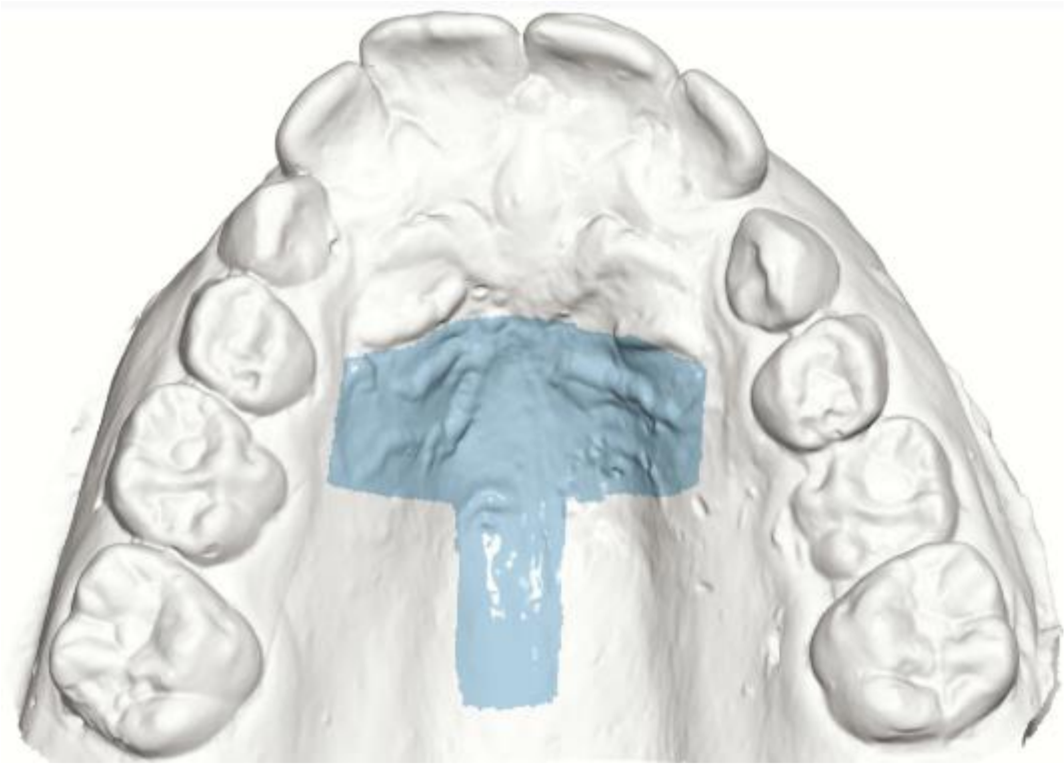


Figure 3.

Superimposition for (T0-T1) period

Superimposition for (T1-T2) period

Figure 4.

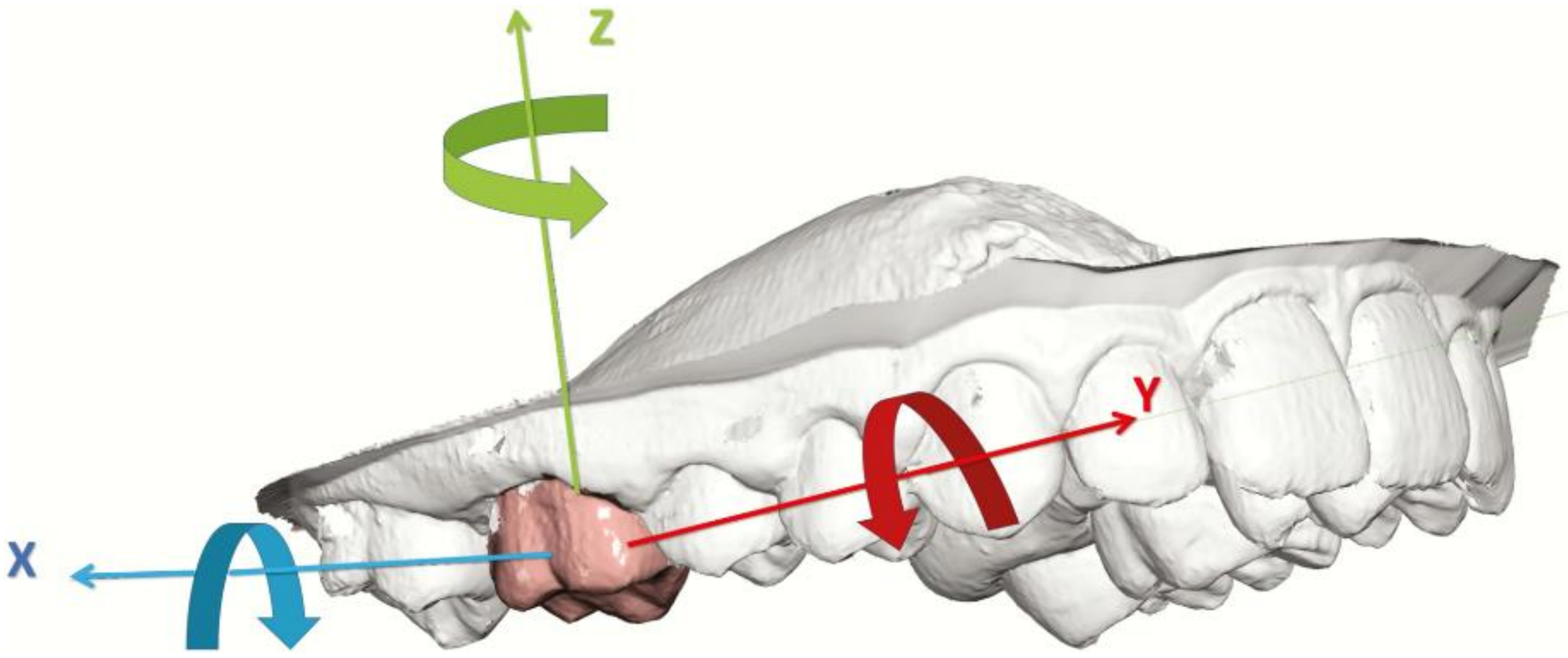


Figure 5.

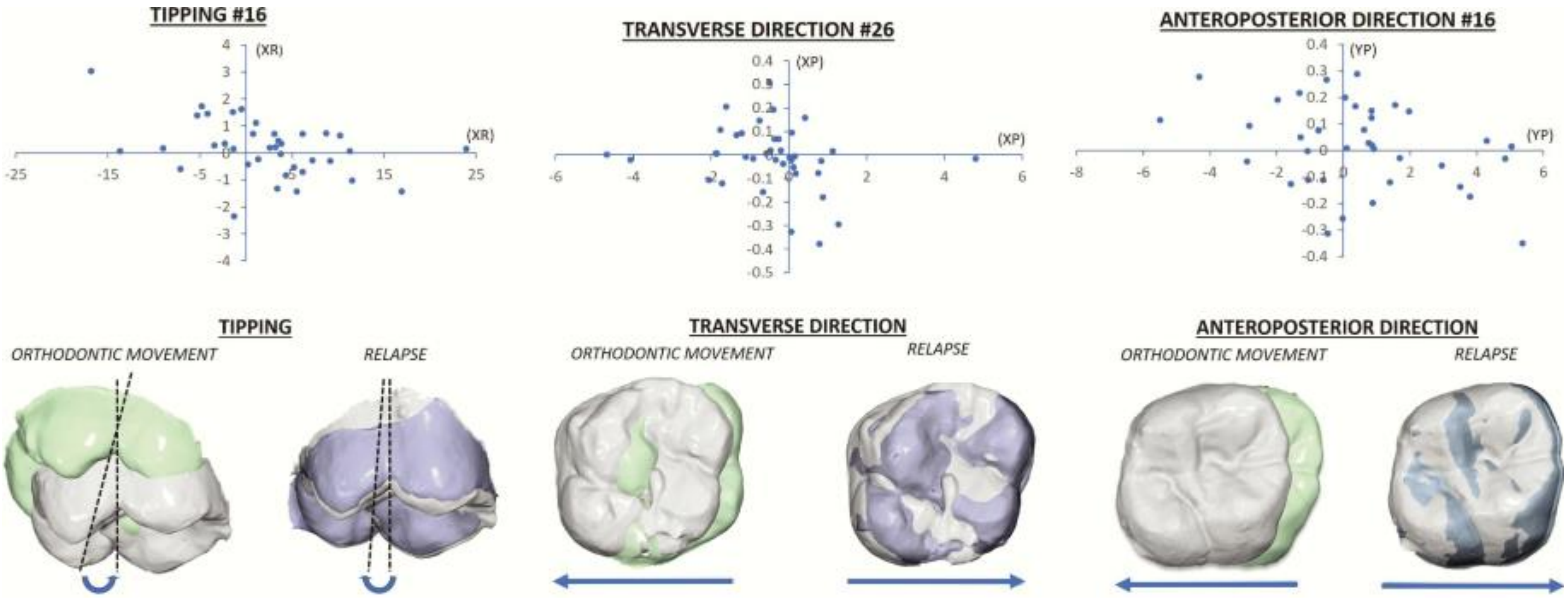
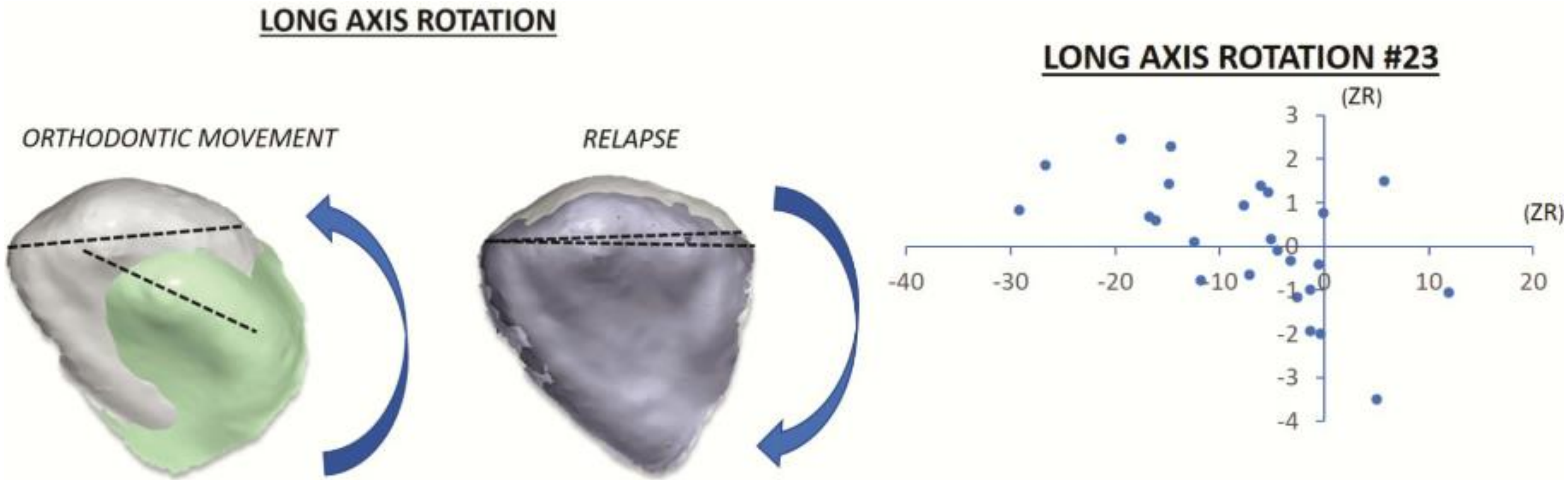
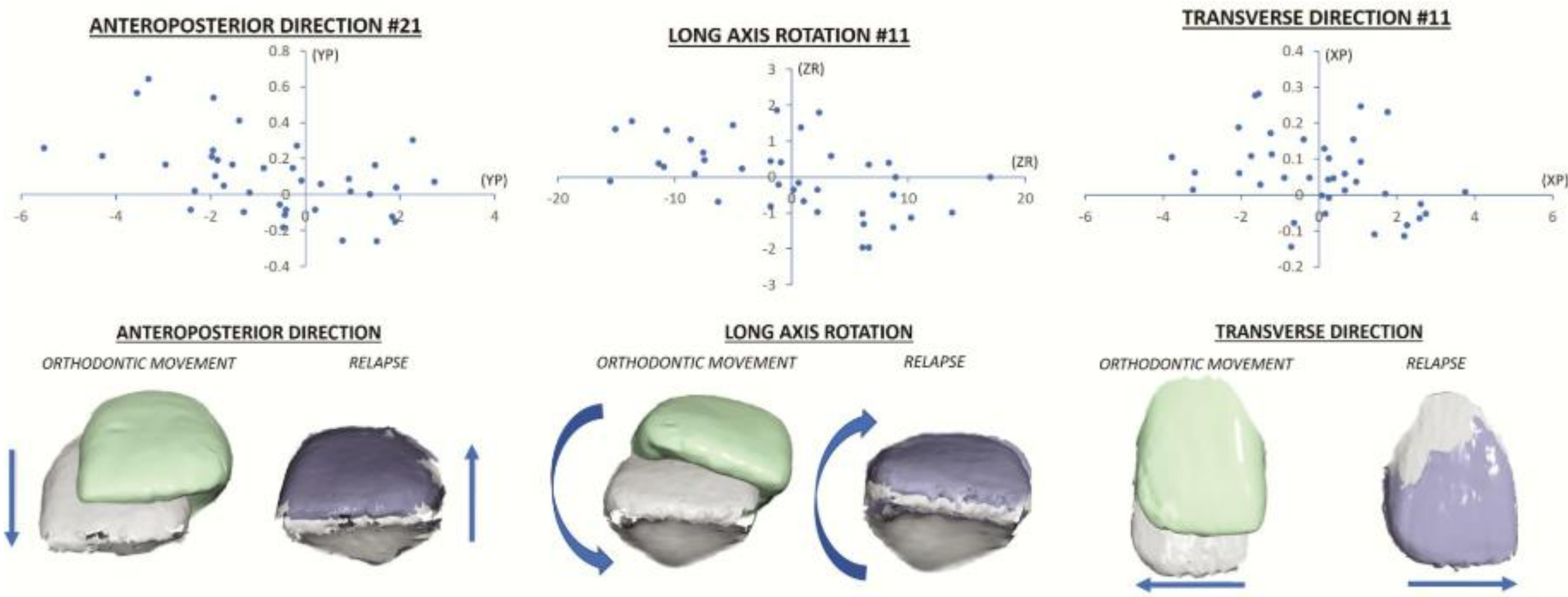

TIPPING #16
(XR)
TRANSVERSE DIRECTION #26
(XP)
ANTEROPOSTERIOR DIRECTION #16
(YP)
TIPPING
ORTHODONTIC MOVEMENT
RELAPSE
TRANSVERSE DIRECTION
ORTHODONTIC MOVEMENT
RELAPSE
ANTEROPOSTERIOR DIRECTION
ORTHODONTIC MOVEMENT
RELAPSE

Figure 6.



LONG AXIS ROTATION
ORTHODONTIC MOVEMENT
RELAPSE
LONG AXIS ROTATION #23
(ZR)
(ZR)
3
2
1
0
-1
-2
-3
-4
-40
-30
-20
-10
0
10
20

Figure 7.



ANTEROPOSTERIOR DIRECTION #21
LONG AXIS ROTATION #11
TRANSVERSE DIRECTION #11
(YP)
(ZR)
(XP)
ANTEROPOSTERIOR DIRECTION
ORTHODONTIC MOVEMENT
RELAPSE
LONG AXIS ROTATION
ORTHODONTIC MOVEMENT
RELAPSE
TRANSVERSE DIRECTION
ORTHODONTIC MOVEMENT
RELAPSE